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Blind to Blinds: Opening Our Eyes to Savings from New Automated Shading Systems

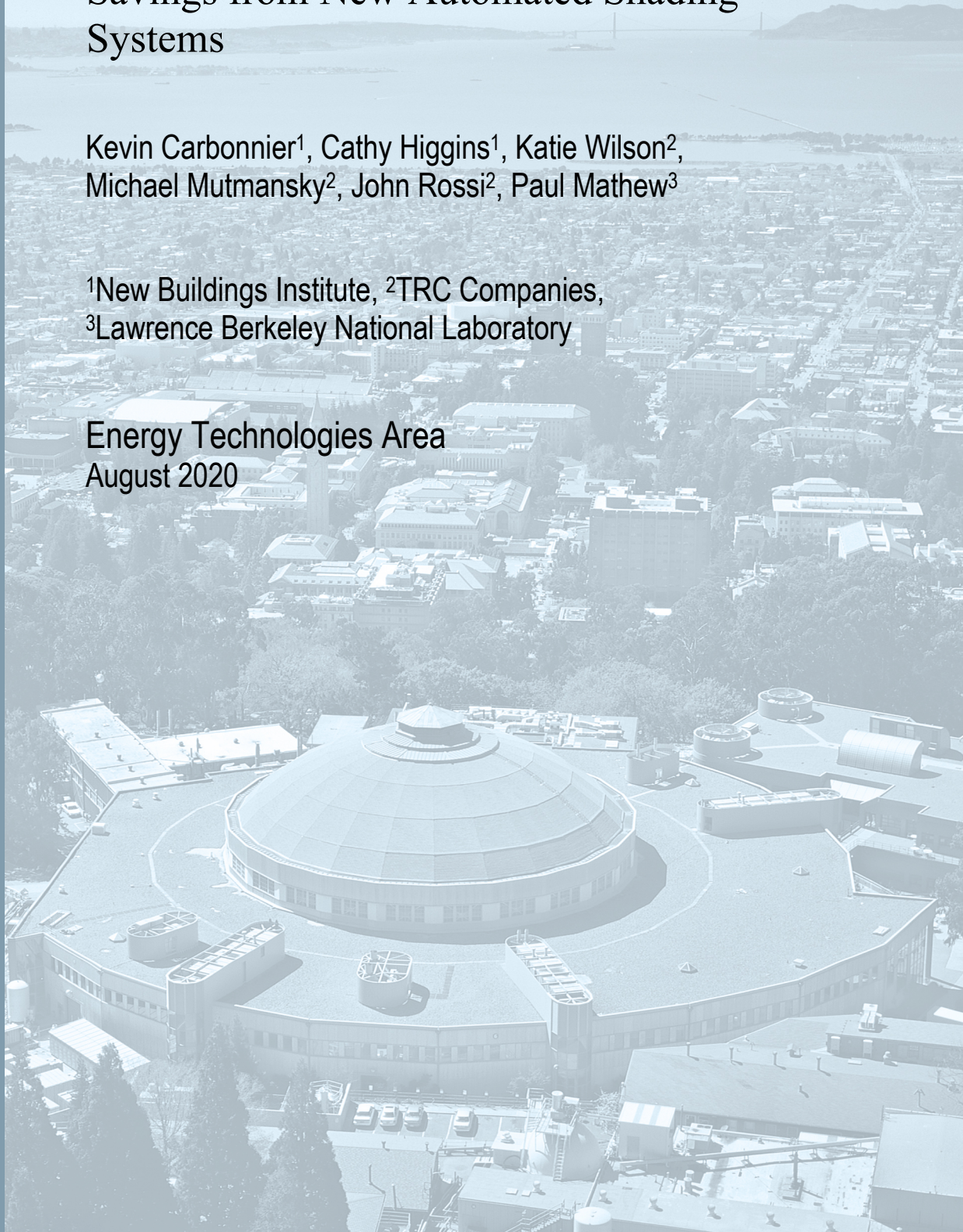
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ABSTRACT

Existing buildings pose a massive challenge to achieving large-scale emissions reductions in the building sector. Effective programs to drive down energy use in the older built environment are lacking, highlighted by the finding that 60% of buildings built prior to 2008 have never been retrofitted (EIA 2012). This largely untapped market presents a tremendous opportunity to save energy and carbon emissions to meet our climate goals.

The “Leading in Los Angeles” project set out to develop a scalable retrofit solution to achieve 20+% whole-building energy savings. The package includes LED lighting with advanced controls, automated interior shading with a daylight redirecting upper portion, and basic HVAC controls commissioning. The lighting and shading systems work together to avoid glare, maximize daylighting, and minimize lighting energy use with dim-to-off automated controls.

This paper presents lab results on the retrofit package and initial metered savings from one office and one higher education demonstration site. At Lawrence Berkeley National Laboratory’s (LBNL) FLEXLAB, we measured significant energy savings attributed to the shades and lighting upgrades. We measured savings in three seasons (summer, fall, winter) against two baselines: 1) typical existing building and 2) Title 24 code compliant building. Lighting savings were significant (49%-76%), and summer cooling load savings was also impressive (19%-38%). Initial field metered results from the demonstration sites are also included in the paper. Most critically, the paper introduces the unique characteristics of the automated shading technology that can serve as a gateway to capture savings in existing buildings.

1. Introduction

Retrofitting existing buildings is paramount to reduce the energy and carbon impact of the buildings sector. The “Leading in Los Angeles” project sought to achieve 20% whole-building energy savings with a semi-customizable retrofit package that the market could scale up and deploy throughout California. The retrofit package includes retro-commissioning of the HVAC system and an LED lighting upgrade with luminaire-level controls coupled with an innovative internal combination shade and louver product. The shade covers the bottom two thirds of the window and the upper louver portion redirects daylight into the space. The building’s centralized control system can control both the angle of the louver and the position of the shade to manage glare and optimize daylighting in the space. Figure 1 details the retrofit package, dubbed the “INTER” system (Integrated New Technologies for Energy-efficient Retrofits).

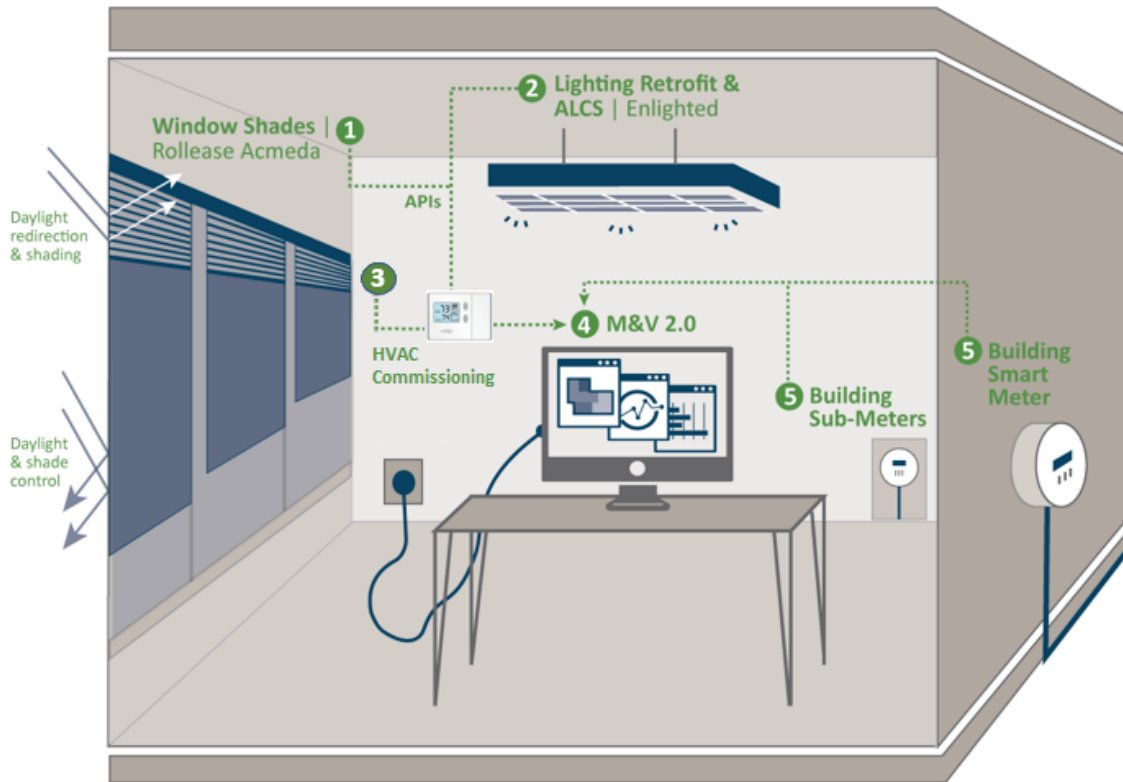


Figure 1. INTER System package diagram. Source: TRC Companies

Spanning three and a half years, the project includes laboratory testing and field demonstration at two sites, including one office and a higher education building. This paper outlines findings in the laboratory testing, initial savings from the field demonstrations, the process for gaining feedback from building owners and occupants as they adjust to their new environments, and challenges to the new system. The closing focuses on the opportunity of shading as a retrofit solution for large scale savings in existing building despite the barriers we must overcome to cost-effectively retrofit the majority of existing buildings.

2. Methodology

Package Development

To reach 20% whole-building energy savings, the project team pursued the end-uses with the most potential for retrofit savings - through lighting, heating, cooling, and ventilation. In California offices, these end-uses account for over 70% of the total energy use (CEUS 2006).

The pre-commercial technology of an integrated louver and shade product allowed us to address both lighting and HVAC savings simultaneously by maximizing daylighting through the horizontal blinds and reducing solar heat gain with the semi-transparent shades (See Figure 1). The deeper daylight penetration pairs well with high-efficacy LED lighting with luminaire-level controls dimming or eliminating electric lighting when there is sufficient daylight at the fixture. LED technology and luminaire-level controls are mature technologies. This research project combined this well-established technology with pre-commercial shading products into a compelling package. Finally, standard HVAC retro-commissioning to tune-up the building and

adjust controls to rebalance the system offers additional savings from the sub-optimal baseline operating conditions in the vast majority of existing buildings.

The package aims to be a “light-touch” installation with limited need for labor from electricians. The shades are self-powered by a battery and integrated solar PV array to recharge the battery, thereby eliminating the need to wire power to each shade. The LED retrofit kits fit into existing lighting infrastructure, which further limits labor requirements in both installation time and complexity.

Site Selection

The project team carefully selected demonstration sites for the project based on several key criteria: a) square footage, b) lighting and HVAC systems representative of the existing building market, c) receptive building owners, and d) located in a disadvantaged community. In addition, the project requirements stipulated the buildings must be governmental, conditioned, served by Southern California Edison or San Diego Gas & Electric, and be located in Los Angeles or Orange County. The TRC Companies team secured partnerships with two building owners to pilot the retrofit package, adding up to approximately 280,000 sf of building area. Table 1 outlines the key site information.

Table 1. Demonstration site characteristics

Name	Building Age	Building Area (ft ²)	Floors	Disadvantaged Percentile (CalEnviroScreen 3.0)
Santa Ana City Hall	50 years	127,000	8	71-80%
Cal State University Dominguez Hills (CSUDH): Welch Hall	19 years	183,000	4	71-80%

FLEXLAB Approach

LBNL’s FLEXLAB test facility allows building systems to be tested individually or as an integrated system, under real-world conditions. FLEXLAB was used to test the INTER system of automated shading products and LED dimmable lighting with daylight controls, comparing it to two baselines: an existing building baseline of non-dimmable fluorescent fixtures on scheduled operation, and a Title 24 baseline of dimmable fluorescents with stepped zonal daylight dimming for the primary and secondary fixtures. The test case (i.e. INTER system) and the baseline cases were tested at the same time under identical conditions using the two cells of the FLEXLAB testbed.

The two main objectives of the testing were to 1) evaluate the energy performance of the INTER system relative to the baselines, and 2) evaluate visual and thermal comfort performance of the INTER system. The test methodology and results are documented in (Mathew, Shackelford, and Regnier 2019) and a summary is provided here.

Table 2 provides the details for the Baseline and the Retrofit test cell configuration and include an existing building and a Title 24 code-compliant baseline with the glazing area as a ‘Full-window’ and with the introduction of physical cover such as cardboard to simulate a “Mid-window” size area. Figure 2 shows a photo of the INTER system test cell.

Table 2. Test Cell Configurations

Description	Both Cells	Baseline Cell			Retrofit Cell		
	Window-to-Wall Ratio	Lighting System	Lighting Dimming Controls	Shading System	Lighting System	Lighting Dimming Controls	Shading System
Full-window, existing building baseline	~ 0.50	Fluorescent: 3-lamp T8 troffers	No daylight-based dimming	Manually operated venetian blinds	LED troffers	Fixture-level daylight dimming	Automated roller-shades and daylight redirecting louvers
Mid-window, existing building baseline	~ 0.40						
Full-window, Title 24 code-compliant baseline	~ 0.50	Fluorescent: 2-lamp T5 troffers	Stepped dimming near windows				
Mid-window, Title 24 code-compliant baseline	~ 0.40						



Figure 2. Photograph of INTER system test cell layout. Automated blinds are set to a neutral angle (0°) and automated rollershades are deployed at a length of approximately 10 inches. *Source:* LBNL

Three test periods of three weeks each (including setup, takedown) were targeted to cover summer, fall and winter periods to capture solstice to solstice solar impacts. The test schedule was managed dynamically over the course of the test period to ensure that adequate exterior conditions (e.g. sunny periods, cloudy periods) were captured for each test permutation.

Demonstration Site Metering

To gather detailed baseline and post-retrofit energy use by end-use, the project team installed sub-meters throughout each of the demonstration sites to support measurement and verification (M&V) of the energy savings from the retrofit technologies. The meters target whole building, lighting, HVAC, and data center energy consumption. The lighting energy sub-metering is further broken out by floor, enabling more detailed analysis within different sections of the same building.

The lighting and shade control systems provide an additional dataset for analysis aside from energy consumption. These systems record the shade position and lighting levels throughout the building, offering insights into the occupant behavior patterns and preferences affecting the building energy use. For example, more than 20 light sensors will be installed at the Santa Ana City Hall building, and every automated shade will log manual overrides to help understand when and how occupants are making overrides to the automated controls strategy. These data streams provide valuable feedback to the building owners and facilities managers to maintain performance and train building occupants on how to best use the systems to suit their needs and save energy.

M&V Approach

The INTER retrofit package affects multiple building end-uses in interactive ways that create challenges to attribute savings to individual technologies within the retrofit package. For this project, the team is applying the M&V2.0 protocol, specifically approaches one and two, developed to provide industry consistency when analyzing large volumes of time-differentiated energy usage data to value the impact of building energy efficiency projects (Franconi 2017).

3. Findings

FLEXLAB Results

Lighting energy savings.

The lighting energy savings of the INTER system relative to an existing building baseline of non-dimmable fluorescent fixtures on scheduled operation ranged from 62% in winter (less daylight dimming possible) to 76% in summer (more daylight dimming). Relative to a Title 24 baseline lighting system equipped with dimmable fluorescents and stepped dimming for fixtures near the windows, lighting energy savings was naturally lower, ranging from 49% in winter to 62% in summer.

Table 3 below provides details on the savings from baseline to retrofit for the configurations and per season. These are savings measured from one configuration (baseline) to an alternate (retrofit) and are not annual whole building estimates. More detailed results are documented in Mathew et al. (Mathew 2019).

Table 3. FLEXLAB energy savings per test case and season (Wh/ft²/day, %)

Savings Type	Test Configuration		Season		
			Summer	Fall	Winter
Lighting Energy	Full Window	Existing Building	10.8 (76%)	10.4 (73%)	9.0 (62%)
Cooling Load			11.0 (36%)	10.9 (28%)	(no cooling)
Heating Load			-1.9 (%n/a)	-1.2 (%n/a)	-2.3 (-17%)
Lighting Energy	Mid Window	Existing Building	10.6 (75%)	10.1 (71%)	9.2 (63%)
Cooling Load			11.3 (38%)	13.9 (43%)	1.1 (100%)
Heating Load			-1.3 (-44%)	-1.6 (-53%)	-2.7 (-27%)
Lighting Energy	Full Window	Title 24 Building	5.3 (62%)	5.0 (57%)	5.0 (50%)
Cooling Load			6.0 (19%)	6.5 (15%)	5.9 (26%)
Heating Load			-0.6 (-18%)	-0.2 (-8%)	-0.3 (-5%)
Lighting Energy	Mid Window	Title 24 Building	5.6 (61%)	4.9 (56%)	5.5 (49%)
Cooling Load			6.7 (25%)	8.8 (24%)	4.3 (76%)
Heating Load			-0.8 (-24%)	-0.2 (-6%)	-1.4 (-16%)

Illuminance and daylight glare.

The lab assessment included measurements to determine if industry accepted levels of illuminance were present in the various retrofit scenarios and if daylight glare was controlled for occupant comfort. The ability to control glare can be a non-energy benefit of shading systems to improve the work environment, particularly for the use of computer monitors. A series of discomfort glare analysis metrics have been developed to predict occupants' acceptance of and preference for competing design solutions, and to evaluate the likelihood of manual blind deployment or automated blind overrides upon occupancy (van den Wymelenberg 2014). For the lab assessment the illuminance design criterion (500 lux) was met in the baseline and retrofit condition.

Visual comfort was evaluated in terms of glare using the Daylight Glare Probability (DGP) metric that considers vertical illuminance at eye level. DGP has been identified as a highly reliable metric, since it was based on experiments with real human subjects (Wienold 2006) and has continued to be a key foundation for daylight analysis by researchers since its inception (Konstantzos 2014). The DGP analysis from the lab test data showed that glare was adequately controlled for all test periods in the baseline case (venetian blinds across window with louvre angle adjusted seasonally to block direct sun) and in the retrofit case (rollershade and redirecting blind angle set seasonally to avoid direct sun).

HVAC energy savings.

HVAC load savings from the shading were found for all configurations when in cooling mode, with HVAC cooling load savings being very close to lighting energy savings, indicating that the majority of the HVAC load difference is due to the lower-wattage electric lighting in the retrofit case (lower wattage lighting results in less heat added to the space). Summer and fall HVAC cooling load savings were consistently higher than energy savings from lighting alone, indicating that the automated shading also contributed cooling energy savings, likely due to solar heat gain reductions from the shades. Some HVAC load penalty (negative savings) was observed while in heating mode, as expected. However, little time was spent in heating due to the test

site's climate, so the results are less robust. For thermal comfort near the window wall, no meaningful difference was measured between mean radiant temperature in the baseline and retrofit cells for most cases (differences typically between less than 0.5 degree F to slightly over 1 degree F).

Retro-commissioning of the HVAC controls is underway but not yet measured. Additional savings from this measure are anticipated as well as benefits in general interoperability and possible extended life of equipment due to the system tuning. This is primarily due to reducing fan operating hours when applying ASHRAE Guideline 36 control sequences with the added occupancy sensor capabilities through the connected lighting system (ASHRAE 2018).

Initial Lighting Savings at the Demonstration Sites

The individual technologies were installed in a staggered fashion to ensure that the lessons learned from one site could be applied to the other. The Santa Ana City Hall location had LED lighting and advanced lighting controls (ALCS) installed first, whereas the CSU Dominguez Hills location began deploying smart shades first. As of March, 2020 the lighting has been installed and mostly commissioned for both site locations. The following preliminary site savings are based only on the installed lighting and advanced lighting controls.

Santa Ana City Hall.

The chart below shows average hourly lighting power for the City of Santa Ana City Hall building from March, 2019 through May, 2020. The lighting project for Santa Ana City Hall began in June of 2019 and installation and commissioning were completed by the end of September, 2019. During the 30 months prior to the retrofit, the lighting's baseline operation is fairly consistent at around 9,700 kWh per week on average. Once the lighting retrofit project began, energy consumption declined as more and more lighting fixtures were replaced with LEDs and the lighting controls were brought into functioning condition. By October, 2019 lighting operation began to normalize into a consistent pattern with an average weekly energy consumption of about 4,400 kWh, for a reduction of 5,300 kWh per week (54%) compared to pre-installation lighting energy use. Assuming steady year-round operation, these two distinct periods can be extrapolated to annual lighting energy baseline and post-retrofit predictions, resulting in an estimated annual lighting energy savings of ~275,000 kWh.

Santa Ana City Hall: Lighting Energy Demand Trend

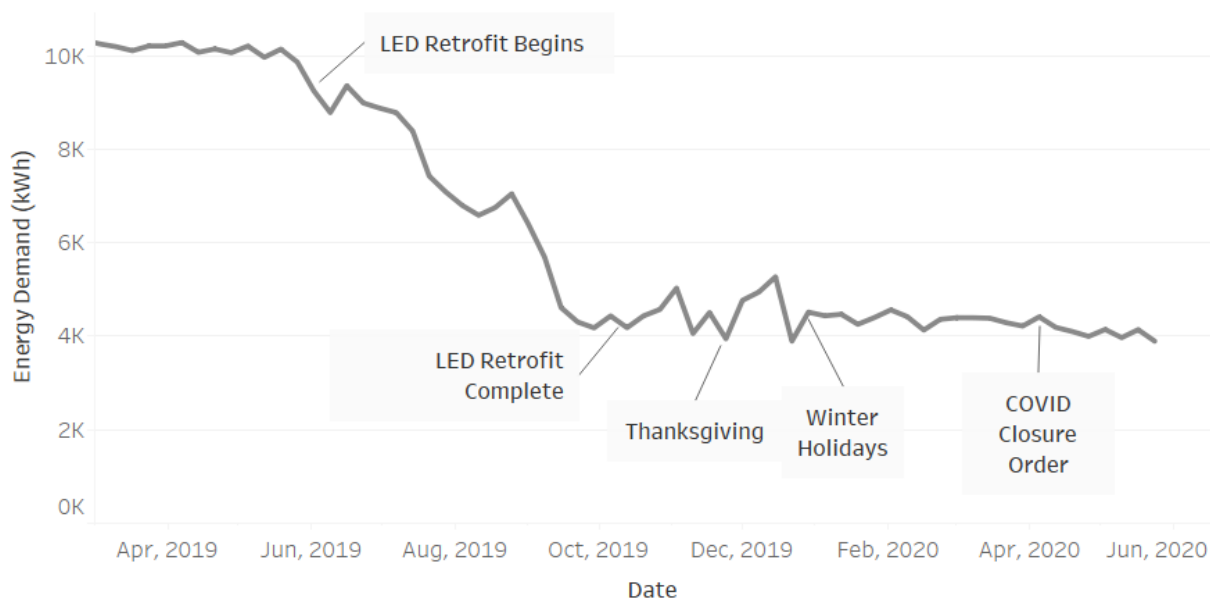


Figure 3. Santa Ana City Hall lighting energy demand by week (kWh). *Source: New Buildings Institute*

California State University Dominguez Hills, Welch Hall

Figure 4 shows average hourly lighting power for Welch Hall from March, 2019 through May, 2020. The lighting upgrade project for Welch Hall began in January, 2020 and installation and commissioning mostly completed as of May, 2020. From December, 2018 through December, 2019 baseline operation is fairly consistent with an average weekly energy consumption of 8,600 kWh. Once the lighting project began, the energy consumption decreased as more fluorescent luminaires were replaced with LEDs. By the end of February, 2020 lighting operation fallen into a consistent pattern with an average weekly energy consumption of 4,700 kWh, for a reduction of 3,900kWh (45%) from pre-installation lighting energy use. Assuming

steady year-round operation, the savings will produce an estimated annual lighting energy savings of ~203,000 kWh.

Welch Hall: Lighting Energy Demand Trend

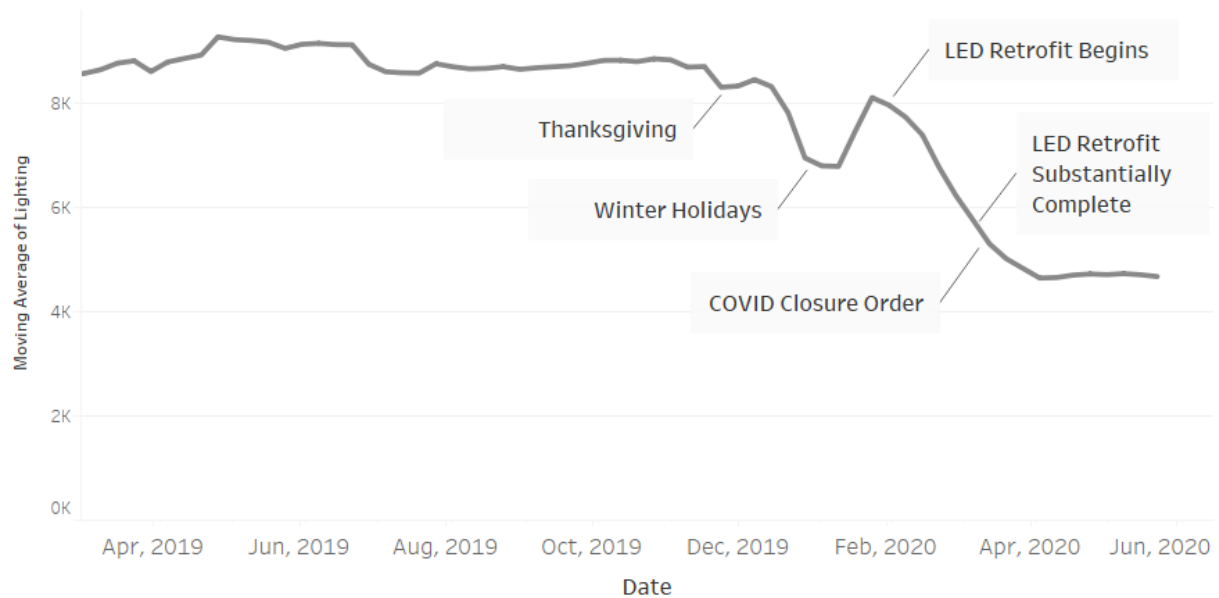


Figure 4. CSUDH Welch Hall lighting energy demand over time (kWh). *Source: New Buildings Institute*

Note that in both these buildings, the HVAC adjustments and final commissioning of the lighting and shades controls have not been completed yet, so we expect further improvements to energy performance as those portions of the project are completed.

4. Stakeholder Surveys

The research project includes three methods of stakeholder input: 1) occupant surveys, 2) interviews with the owners and contractors, and 3) manufacturer interviews in order to inform the technology's market potential. At the time of this paper the project team has conducted part one of item one, a two-phase occupant survey using an online tool that assesses occupant's responses to a variety of indoor environmental quality factors (UC Berkeley 2019) with the addition of a small set of customized questions relative to the shading and window perceptions. The first online survey of occupant perspectives was during the pre-retrofit conditions and the team will conduct the same survey 3-6 months post-retrofit.

In addition, for stakeholder area two, the research is undertaking direct interviews with the parties involved in the installation (contractors) and the ownership (owner and/or facility manager) to identify process, product and installation issues and benefits that can help drive design modifications, ease installation costs, and support market messaging. Lastly, the findings from the first two stakeholder feedback methods will be combined with the energy savings to engage the specific manufacturers of the demonstration products, as well as those of similar products, to solicit suggestions for product evolution and market advancement.

Preliminary Anecdotal Feedback

At Santa Ana City Hall, the immediate feedback from the lighting upgrade is positive. For example, the new LED lighting and advanced controls have led to several occupants remarking that “they enjoy the dimming controls” and that “it is nice to have the space calibrated to my liking!” One facility lead stated that a minor downside was that the improved color rendering of the new lighting made it quite obvious how faded the carpet was in a particular space.

The new smart shades users are now utilizing advanced hubs to directly control their assigned shades. Every aspect of the shade control can be overridden by the individual users, however, each day the shades reset to provide optimum performance for glare reduction and daylight harvesting based on time of year. They have been well received by the staff for the aesthetics and controls. For example, one occupant stated, “I really enjoy being able to let natural sunlight into my space with just a push (of a button).” Another user could not believe how much brighter the new shades coupled with an exterior screen removal made their office space. CSUDH has not had the installation in place for a sufficient length of time for user assessment. The findings from the full set of stakeholder feedback will be a part of the overall research study findings report anticipated in mid-2021.

5. Challenges and Solutions to System Integration and Adoption

While technology barriers are mostly resolved for the systems, barriers to the INTER concept do exist that must be overcome to accomplish retrofits of this type at scale in the largest group of candidate buildings – basic commercial office buildings. Most of the barriers and opportunities can be characterized as one of four areas described below.

Awareness and Training

The approach includes sophisticated lighting and shades technology and systems design unfamiliar to the typical teams responsible for designing and implementing retrofits. Further, owners and facility managers will not be familiar with controlling automated shading and what it may take to keep the hardware operating properly. Programs and manufacturers can provide solid assistance by creating design and operational guides, training programs and case studies. Some of these will be a part of the final research outcomes from this Leading in LA study.

Internet Technology Integration

These systems are connected via ethernet or wireless communication system to enable the interactive scheduling, controls interactions, and monitoring. The IT department controls the communications rooms where most of the hardware in the lighting and shades controls will likely reside and IT staff are often protective of the equipment placed in ‘their’ area. Even if the equipment is completely independent of the rest of the building IT network, IT staff may require involvement to ensure that the hardware and other details meet the security requirements needed to ensure the safety and security of the communications infrastructure.

Work is needed to develop an arrangement of security capabilities and other communications protocols that will be readily accepted by the IT departments without the need for high levels of scrutiny. Similarly, the equipment selection for installation in the IT rooms and

the hardware that is deployed throughout the building must meet the level of performance expected by the IT Departments to ensure ready acceptance on the project and within the IT rooms. Work needs to be done to create a dialogue with the IT community to further this understanding and develop viable specifications and hardware selections to enable fast-track deployment in buildings. Projects can look to lessons learned from research on IT integration with Wi-Fi enabled controls for energy efficient technologies.

Ownership and Facility Management Alignment

Organizational structure may also factor into the viability of the project. In an organization that has a suitable structure, the control of the real properties of the company will not be controlled wholly by the Facilities Department but will certainly have input from that department. Some Facilities Departments are unwilling to trade annual budget that is earmarked for operational expenses (electricity and other utility billing) toward a capital expense project such as the INTER system because it reduces the available budget under their control. Another ownership barrier for the INTER system is related to the split incentive problem associated with leased office spaces. The property owner may be unwilling to commit to an INTER approach for the facility because the changes involve added cost and complexity that they are not going to see in their bottom line. This, again, is another situation where it is imperative that the conversation include the Facilities Department early in the project discussion phase and assess the financial conditions critical to the owner.

Cost

The cost associated with the technology and sophisticated hardware involved in an INTER retrofit may be a significant barrier for implementation for most properties, even with incentives offered by utility programs. Cost barriers are coming down as the technology advances and the market adoption normalizes the products. The goal of developing the INTER system is that the products and design approach can be commoditized enough that there will be savings associated with simplifying the process, reducing the range of products to increase volume for economies of scale, and simplify and standardize the installation so that the hardware can be installed in a fast and efficient manner. The cost of installation will also improve as installers become more familiar with the systems. This, along with the technology market adoption pricing curve will push the cost of the installed systems down and into the realm of viable options for most commercial office buildings in the future.

6. Getting to the Gateway

Getting into existing buildings for deep energy retrofits is a long-standing hurdle for efficiency programs and contractors. The automated shading component offers a gateway technology to retrofits because it provides benefits that go beyond the anticipated energy savings for the building (which are considerable on their own) to address tenant needs with a highly visible and attractive product. The case can be made for the shades independent of energy efficiency. The preliminary evaluation of occupants seems to indicate that the lighting and shading changes are very positively received for several aspects of the workplace environment, including visual comfort, overall satisfaction, improved views, and better user-control. Interior environment upgrades can also increase the space value in a competitive real estate market.

Using these system attributes to attract interest and address a physical space need takes the focus away from payback based solely on energy savings.

Other benefits of the INTER concept are evolving to support the case for the full system - the lighting system and the shades both can be developed into simplified hardware selection packages that will help reduce the complexity of the design process for a retrofit project. Since building retrofit work typically has low margins, streamlining the design process and reducing tenant disruption will enable more and deeper retrofit activity. The packaging approach can be developed for typical buildings within a viable range of prototypes and climate zones, and once completed, a retrofitter could implement one of a small number of product selection choices for each technology and be confident in the savings without having to make complicated daylighting calculations for a selected shading and lighting system.

As we put a spotlight on these features and benefits building owners and occupants will be less blind to blinds. Controlling the characteristics of glazing with automated shading could be the gateway technology to deep integrated retrofits in the next generation of programs.

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